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Generation and dynamics of large scale flows in magnetized plasmas and rotating fluids

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The self-consistent generation of large scale flows - zonal flows - by the rectification of small scale turbulent fluctuations is of great importance both in geophysical flows and in magnetically confined plasmas. These flows, which are generally sheared, will regulate the turbulence by suppressing the small scale structures and set up effective transport barriers. The purpose of this presentation is to discuss the morphology of zonal flows, the basic mechanisms for their generation and their influence on turbulence and the associated transport in magnetized plasmas and rotating fluids.

In the geophysical context the large scale flows appear as zonal jets in the atmospheres of rotating planets, or at smaller scales as mean flows over topography in oceans and atmospheres. We will illustrate zonal flow generation in a simple fluid experiment in a rotating tank with radial symmetric bottom topography. The bottom has a constant negative slope, β, in the radial direction and the so-called potential vorticity $PV = \omega + \beta r$ is a Lagrangian conserved quantity (ω is the relative vorticity). An effective mixing that homogenises PV will lead to replacing the high PV near the centre with low PV from the outside, and this will appear as an anticyclonic vortex over the centre, hence a large scale flow. The experiment is modelled by the quasi-geostrophic vorticity equation in the β-plane approximation. This model equation is equivalent to the Hasegawa-Mima equation describing drift wave dynamics in magnetized plasma. Thus, the mechanism for the formation of zonal flows in magnetized plasmas may be equivalent to the one in rotating geophysical flows.

In magnetically confined plasmas it is now generally recognized that sheared poloidal flows strongly reduce the radial turbulent transport and are instrumental in the rapid transition to an enhanced confinement (the H-mode) now routinely observed in larger tokamaks. We review recent investigations of zonal flow generation in electrostatic, low-frequency turbulence and emphasise the self-consistent interaction of the flows and the small scale turbulence by discussing the energy transfer between the flows and the turbulence. In electrostatic turbulence the Reynold stress (Re) is the main source of interaction between large-scale flows and small-scale turbulence, which is verified both in experiments and numerical simulations. When electromagnetic effects become important for finite beta plasmas, an additional source of flow generation must be taken into account: the so-called Maxwell stress (Ma), which, however, is acting as a sink for the flows.